IRON MINING METHODS AND COSTS, GREENWOOD MINE, ISHPEMING, MICH.

By R. C. Annear and W. A. Cole

* * * * * * * * * * * * information circular 7971

UNITED STATES DEPARTMENT OF THE INTERIOR
Fred A. Seaton, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director

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MINING METHODS AND COSTS, GREENWOOD MINE, ISHPEMING, MICH.[1]

By

R. C. Annear[2] and W. A. Cole[3]

SUMMARY

This report describes open, sublevel, and shrinkage stoping at the Greenwood mine, operated by Inland Steel Co. The iron ore mine is in Marquette County, Mich., about 6 miles southwest of Ishpeming (fig. 1). The Greenwood is one of three active underground hard-ore mines on the Marquette range, the others being the Cliffs-Shaft and the Champion mines.

The operation reflects an achievement in exploiting small, difficult-to-mine hard-ore bodies lying beneath a 200-foot overburden of glacial drift, which is partly water bearing. This report can indicate only briefly the efforts of personnel in overcoming adverse conditions in mining more than 2 million tons of ore, 80 percent of which was in lump form, for open-hearth production of steel.

Significant data presented include descriptions of the principal mining methods employed, sublevel and shrinkage stoping; percentaged mining costs for the entire year 1957, covering both direct mining costs and general expenses; and performance records in units of labor, power, and supplies.

INTRODUCTION

This is one of a series of reports dealing with mining methods and costs, particularly costs in terms of performance, of mines in the United States to be published by the Federal Bureau of Mines. A similar program was conducted from about 1928 to 1939 with the same primary purpose of promoting the development and conservation of our mineral resources by the dissemination of technological information on methods, practices, and related features in mining mineral deposits.

The principal objective in the current program is to provide up-to-date factual performance and cost data, together with mining operational case

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1/ Work on manuscript completed June 1959.
2/ Superintendent, Morris Mine, Inland Steel Co., Ishpeming, Mich.
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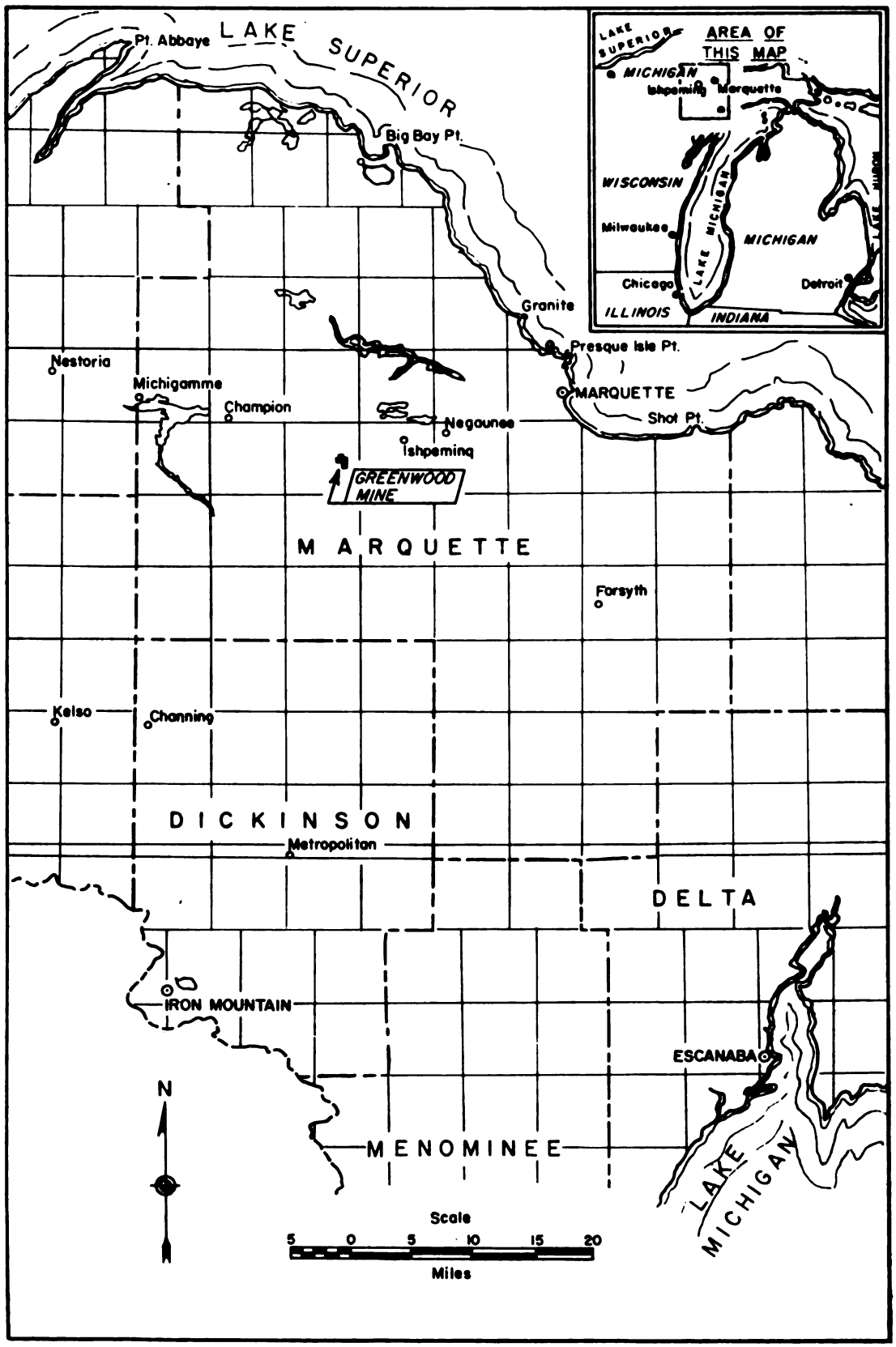

FIGURE 1. - Location Map, Greenwood Mine, Marquette County, Mich.

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histories, essential in the application of research developments by both private and government agencies.

Although the Greenwood mine is a relatively small operation, its importance is considerably enhanced because it produces lump iron ore, a premium-priced product that is not in plentiful supply in the United States.

ACKNOWLEDGMENTS

In behalf of the Bureau of Mines the authors are deeply grateful to R. D. Satterley, vice president and general manager, and H. M. Graff, former manager, Ore Mines, Inland Steel Co., in assigning a supervisory staff member as coauthor, and for supplying and permitting the use of production, performance, and other data covering operations at the Greenwood mine.

Appreciation is expressed for the courtesies extended and assistance given in a review of the report by Philip D. Pearson, manager of Ore Mines, and Dr. Alan T. Broderick, geologist, Inland Steel Co.

HISTORY

The property was leased by Inland Steel Co. in November 1929. Originally, the site had been test-drilled for the Jones and Laughlin Steel Corp. by the E. J. Longyear Co. about 1912. After Inland Steel acquired the property and ran a more extensive drilling program in 1928 and 1929, it was decided to sink a vertical shaft. A contract was let to the New York Foundation Co. to sink a concrete-lined shaft to ledge. The work was begun in September 1930. After a month, water inflow necessitated working under pressure, and by the time the ledge was reached, the sinking crew was working under 45 p.s.i.

The sealing job at ledge was completed in February 1931, and crews of Inland took over and sunk to the 1100 level.

In 1936, the shaft was sunk to the 1300 level, in 1938 to the 1500 level, in 1940 to the 1700 level, and in 1947 to the 1900 level, which is the bottom level at present.

The first boatload of ore was shipped in October 1932. Through 1956 the mine shipped 1,998,329 tons of ore with an average natural analysis of 57.49 percent iron, 0.163 percent phosphorus, 10.06 percent silica, 0.07 percent manganese, 0.029 percent sulfur, 4.17 percent alumina, and 1.21 percent moisture.

Present stoping is on the 1500, 1700, and 1900 levels. Stopes are confined in a zone that extends three-quarters of a mile east and west and vertically underlies the northern part of the N1/2 NE1/4 and NE1/4 NW1/4, sec. 23, T. 47 N., R. 27 W. In addition to this land, leased land comprising the Greenwood property includes the SW1/4 SE1/4, sec. 14 and SE1/4 NE1/4 sec. 23 in T. 47 N., R. 27 W. The last major exploration drift was driven west on the 850 level in 1957. Mine shipments are given in table 1.

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TABLE 1. - Greenwood mine shipments

Year	Long tons	Year	Long tons
1932	5,053	1945	107,284
1933	22,095	1946	84,273
1934	52,395	1947	98,017
1935	68,310	1948	94,748
1936	35,502	1949	112,598
1937	37,659	1950	86,471
1938	29,556	1951	69,695
1939	61,870	1952	100,956
1940	103,638	1953	91,330
1941	94,565	1954	85,942
1942	121,809	1955	81,578
1943	134,116	1956	63,241
1944	155,627	1957	40,256
		1958	85,188

DESCRIPTION OF DEPOSITS

Geology

The geology of the Marquette range will be discussed in some detail, inasmuch as this paper is the first in a series of Information Circulars on mining methods employed in the district.

Structure

The iron formation is in a series of sediments lying on a rock complex of Lower Precambrian igneous and metamorphic rocks. In general, the major structure of the range is a westward-pitching synclinorium open at the west end. For practical purposes, it may be said the synclinorium extends westward some 40 miles from the vicinity of the city of Marquette. In the western part of the district, Michigamme Lake and Michigamme River exhibit structural control of their origins by their positions. The northern, or main, part of the lake trends east and west parallel to the strike on the north limb of the synclinorium, which continues on westward, extending some 6 miles into Baraga County. The south arm of the lake lies in a crossfold of considerable magnitude that appears to divert the westward trend of the south limb of the synclinorium, which is folded into a tight trough and extends in a narrow band down the Michigamme River to the town of Republic.

This synclinorium is of peculiar and complicated character. Superimposed upon the larger folds are folds of lesser orders. Along the outer borders in much of the district sharply overturned folds plunge steeply toward its axis. Although the more conspicuous folds of the district have in general an east-west axis, the rocks have also been under strong east-west compression; as a consequence, the folds are buckled so that many of them pitch steeply.

Faulting is extensive in some localities, and minor fracturing or jointing is prevalent. It may be pertinent to the miner to point out that the same

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forces that caused the formations elsewhere may have extensively fractured them locally, even in areas where folding is not evident.

Igneous rocks of different ages intrude the Precambrian formations in the district. Post Huronian (post-Animikie) intrusives are in greater abundance in the iron formation.

Stratigraphy

Figure 2 indicates relative thicknesses of the formations on the Marquette range. It will serve also as a generalized stratigraphic section of the sediments. In recent Federal Geological Survey work in Upper Michigan, changes in stratigraphic terminology have been made.[4] The Animikie has been given series rank in application to the heretofore called Huronian strata for part of Michigan (Iron and Dickinson Counties). Extension of the term Animikie rather than retention of the term Huronian for strata of the Marquette range has been advocated.

There is a considerable variation in the thickness and rock types of the various units, as indicated in figure 2. It was based on data from the records of the four mining companies presently producing ore on the range, and was prepared by Burton H. Boyum.[5]

The Negaunee formation is the principal iron-bearing formation of the Marquette range. It ranges in thickness from practically nothing to its normal maximum thickness in excess of 2,000 feet in the Ishpeming-Negaunee area, not including the large masses of basic intrusive occurring within the iron formation. The intrusive rocks, approximating diorite in composition and grain size, have been identified in three principal sill-like sheets in the Ishpeming-Negaunee area. The sills have a maximum thickness of some 700 feet, and a general average of perhaps 400 feet.

Origin of Lake Superior Iron Ores

Opinions pertaining to ore genesis advanced by leading geologists in studies of Lake Superior iron ores have been summarized by Stanley A. Tyler.[6]

More or less general agreement upon the following points was noted among the more recent workers:

1. The iron formations of the Lake Superior region were originally composed dominantly of silica, with important but subordinate quantities of iron carbonate, iron silicate, iron oxide, and iron sulfide.

4/ James, Harold L., Stratigraphy of pre-Keweenawan Rocks in Parts of Northern Michigan: Geol. Survey Prof. Paper 314-C, 1958, pp. 27-44.

5/ Boyum, Burton H., The Geology of the Marquette Iron Range, ch. in Fourth Mining Geology Symposium, Minneapolis, Minn.: University of Minnesota Center for Continuation Study, 1954, pp. 3-8.

6/ Tyler, Stanley A., On the Origin of the Lake Superior Iron Ores, ch. in Proc. of an Inst. on Lake Superior Geology, Minneapolis, Minn.: University of Minnesota Center for Continuation Study, 1955.

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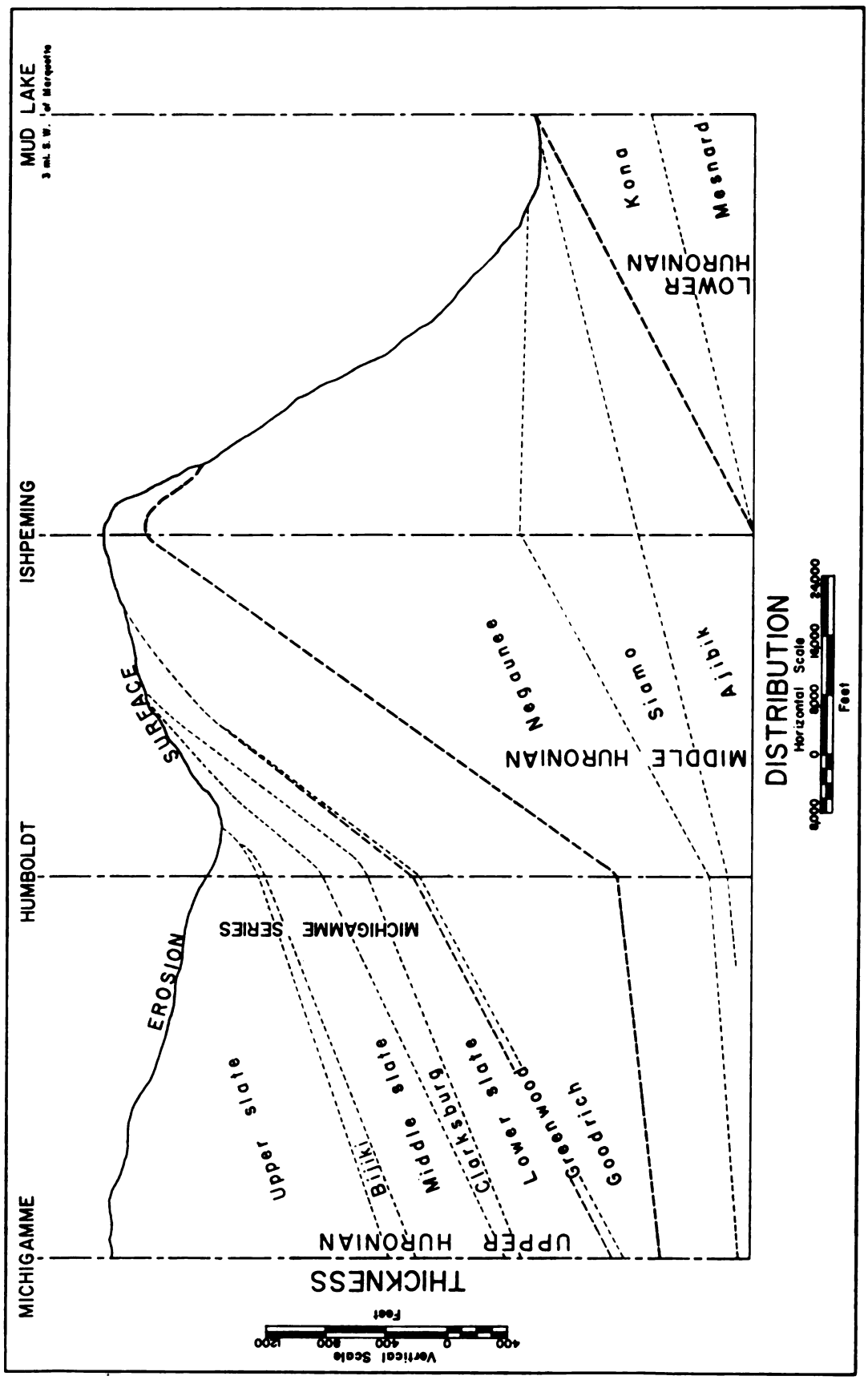

FIGURE 2 - Graph Showing Relative Thicknesses of Huronian Sediments on Marquette Range, Mich.

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2. The iron ore is largely a residual product formed by oxygen-bearing solutions, which oxidized the ferrous minerals to the ferric state and removed the silica in solution.

3. Migration of iron and replacement has played an important part in the development of some, perhaps many, ore bodies.

4. Fractures, faults, joints, breccia zones, bedding planes, dikes, sills, and impervious sedimentary horizons have exerted a marked control upon the path that the ore-forming solutions took through the iron formation.

5. The period of ore formation was largely, if not entirely, restricted to the Precambrian.

In contrast, there is a general lack of agreement as to whether the solutions that oxidized the iron and leached the silica were rising hydrothermal waters or cold descending meteoric waters.

Inasmuch as the iron formation is a sedimentary rock, which is sensitive both to the presence of oxygen and to the loss of silica, it has been concluded by many that the ores may have formed at different times under differing environments.

Physical Characteristics of Ore and Enclosing Rocks

Type of Ore Bodies

The high-grade iron-ore occurrences of the Negaunee formation may be divided according to stratigraphic position into three general types: (1) soft-ore bodies at the bottom of the formation, which is the most important type at present; (2) soft-ore bodies within the formation; and (3) hard-ore bodies in the top layers of the Negaunee formation and at the basal horizon of the Goodrich formation locally present as conglomerate.

Size of Ore Bodies

The size and shape of the ore bodies are related closely to structure. In fact, the consensus of geologists in the district credits structural features as the predominant control affecting magnitude.

The principal structures of typical ore bodies in the three categories previously mentioned will be discussed briefly:

1. Soft-ore bodies at the bottom of the Negaunee. These are generally found in the synclines and in fault structures bounded by intrusive dikes along at least one side. These deposits may be as great as 260 feet normal to the bedding and have considerable lateral extent, some ore bodies being large enough to be mined by the block caving method of stoping. The footwall is Siamo slate or Ajibik quartzite.

An extension of this type is that of "ore pipes" or chimneys of ore extending from the footwall some distance vertically, across the stratified

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iron formation. Larger ore deposits in this category are localized in the intersections of two or more dikes cutting the iron formation, and are characterized by "heavy ground."

2. Soft-ore bodies within the iron formation. These occur on large intrusive sills near the upper part of the iron formation. Deposits of this type were some of the first to be exploited in the Ishpeming area, principally south of Ishpeming toward the axis of the synclinorium. Ore bodies were of irregular distribution and thickness, limited largely by the same structural controls as the ores lying on the footwall contact.

A number of mines were producing large tonnages of iron ore from deposits in this category 50 years ago. One ore body in the Lake Angeline mine was reported to be the greatest of the Marquette district, containing many millions of tons of ore.7/

3. Hard-ore bodies. The footwall of the hard-ore bodies may be unoxidized iron formation, oxidized iron formation of the "jaspilite" type, or "hard-ore jasper," or one of the intrusive sills. The hanging wall may be of the "hard-ore jasper" type, material of the Goodrich formation, or less frequently intrusive material.

The Greenwood ore bodies are small, ranging from small pockets and narrow stringers to the maximum width of 60 to 70 feet and length of about 200 feet. Generally the ore bodies are 50 to 100 feet long and up to 40 feet wide. Continuity of the ore on the dip usually is about the same as the measurement of the lateral extent. However, a westerly plunging trend is indicated in the overall grouping of the ore lenses.

In the Cliffs-Shaft mine, ore occurrence is irregular, ranging from 25 to 150 feet in thickness. Inclination of the ore beds varies between 0° and 60° due to folding and structural pitching.8/

The magnitude of high-grade soft-iron ore deposits is related to folding, faulting, and diking, primarily in respect to control of secondary oxidation, leaching, and replacement. The large soft-ore bodies occur in pitching troughs formed by synclinal folding, by a diorite sheet and its conjunction with a dike, or by either of the latter two structures and union with a sedimentary slate member.

Structural features also have played dominant roles in magnitude of hard-ore bodies, although the relationship is not so easily explained and may be a subject of conflicting opinions. The Cliffs-Shaft mine on the north limb of the synclinorium at Ishpeming is an example of a large hard-ore deposit occurring largely in a westerly plunging syncline having a crossfold under the town

7/ Mead, W. J., The Iron Ores of the Marquette District, ch. in The Geology of Lake Superior Region: Geol. Survey Mono. 52, p. 271, 1911.

8/ Lewis, Walter E., Carbide Insert Bit Drilling at the Cleveland-Cliffs Iron Co. Mines, Ishpeming, Mich.: Bureau of Mines Inf. Circ. 7558, 1950, p. 4.

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of Ishpeming. Anticlinal folding and faulting localized some of the Greenwood ore bodies.

At the Greenwood and Champion mines, thin, rich hard-ore bodies occur in the upper part of the Negaunee and in the basal member of the Goodrich formation. The ores were developed, in part, as a thin mantle at the erosion surface during middle-Huronian times. Marquette range ores so localized stratigraphically are relatively high in alumina, commonly 4 to 5 percent, probably the result of environmental conditions under which chemical weathering took place. Possibly the thickness of the deposits was enhanced where folding or faulting had locally elevated the iron formation in pre-Goodrich times. Mead[9/] attributes the alteration of the ore to the specular variety to folding, which followed the deposition of the upper Huronian and preceded the great period of soft-ore concentration.

Greenwood Ore Bodies

The larger ore bodies at the Greenwood mine are described as being developed within the uppermost layers of the Negaunee formation. A minor amount of detrital ore has been mined from the Goodrich. These formations and their contained ore bodies dip 60° to 75° north.

The geologic relationships of the Greenwood ore bodies are shown in figure 3. Sills, dikes, and irregular dioritic masses are associated with thin, hard-ore bodies in the upper layers of the Negaunee. Some of the major ore bodies are in anticlinal folds, and some drop away from the hanging wall along fractures.

The presently known top of the iron-bearing formation, some 150 feet in thickness, is essentially specular-hematite-chert with or without sericite. Irregular masses of magnetite-chert are associated with magnetite ore. Magnetite-iron silicate-chert constitutes much of the lower portion of the Negaunee iron formation in the Greenwood area. This rock is the metamorphosed equivalent of the soft-ore horizons.

The magnetite-iron silicate-chert consists of alternating bands composed of varying proportions of the minerals magnetite, grunerite, garnet, and quartz.

In some of the larger stopes the following relationships are common. Between the Negaunee iron formation and overlying Goodrich formation a thin sill or sheet of diorite has been intruded. Conglomerate is present in places, forming the basal member of the Goodrich. Below the sill are found thin ore bodies of specular hematite. Some deposits are not of minable thickness, or thin dikes and discontinuous irregular masses related thereto transverse them. Other deposits, particularly west of the crosscut to the shaft, locally attain a maximum thickness of 60 to 70 feet.

Figure 4 shows an east-west longitudinal section of the western portion of the mine. The stopes are indicated by crosshatching. It will be noted

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9/ Work cited in footnote 7, p. 278

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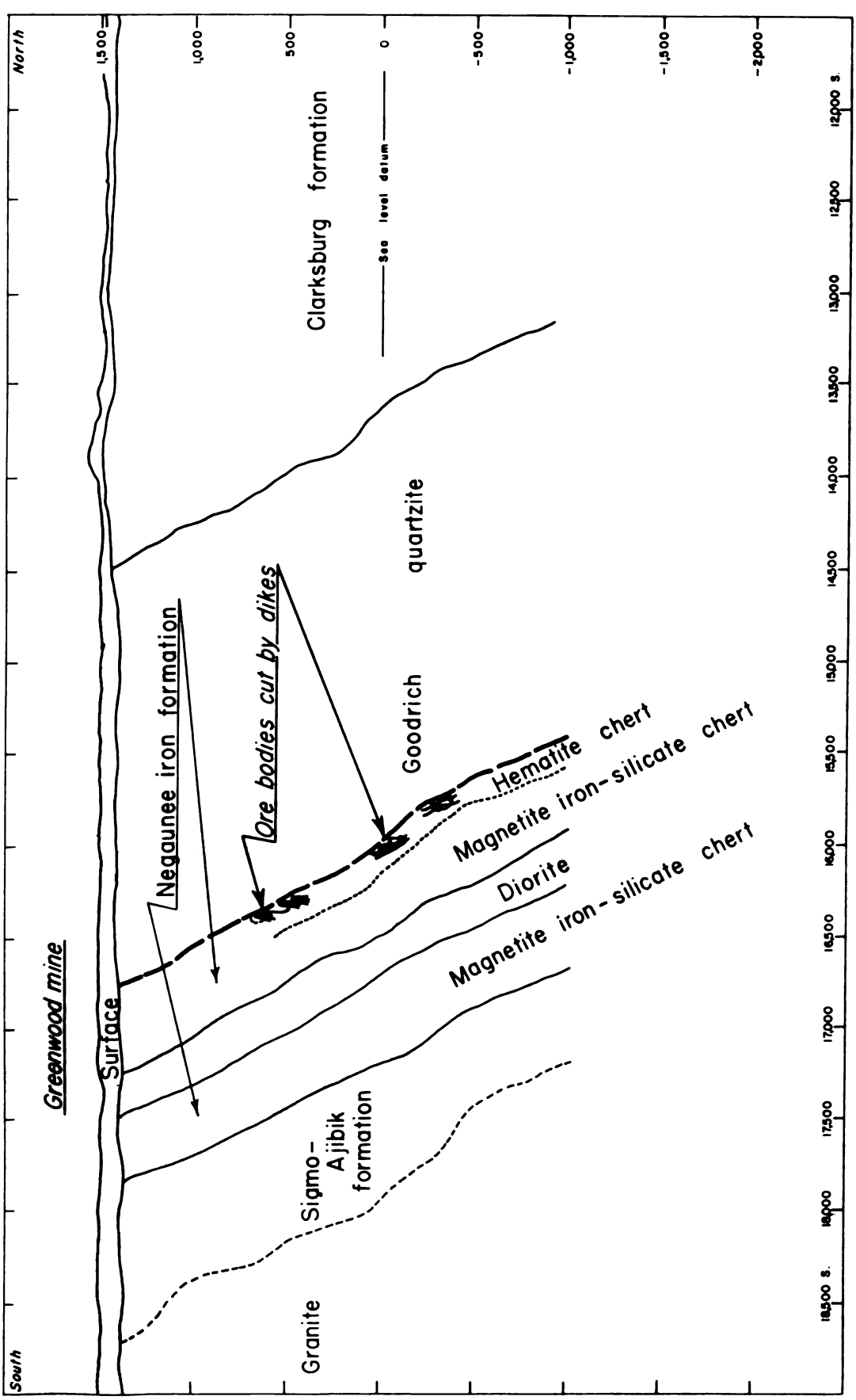

FIGURE 3. - Generalized North-South Section Along East 16th Line of Sections 14 and 23, T 47 N, R 28 W, Looking West.

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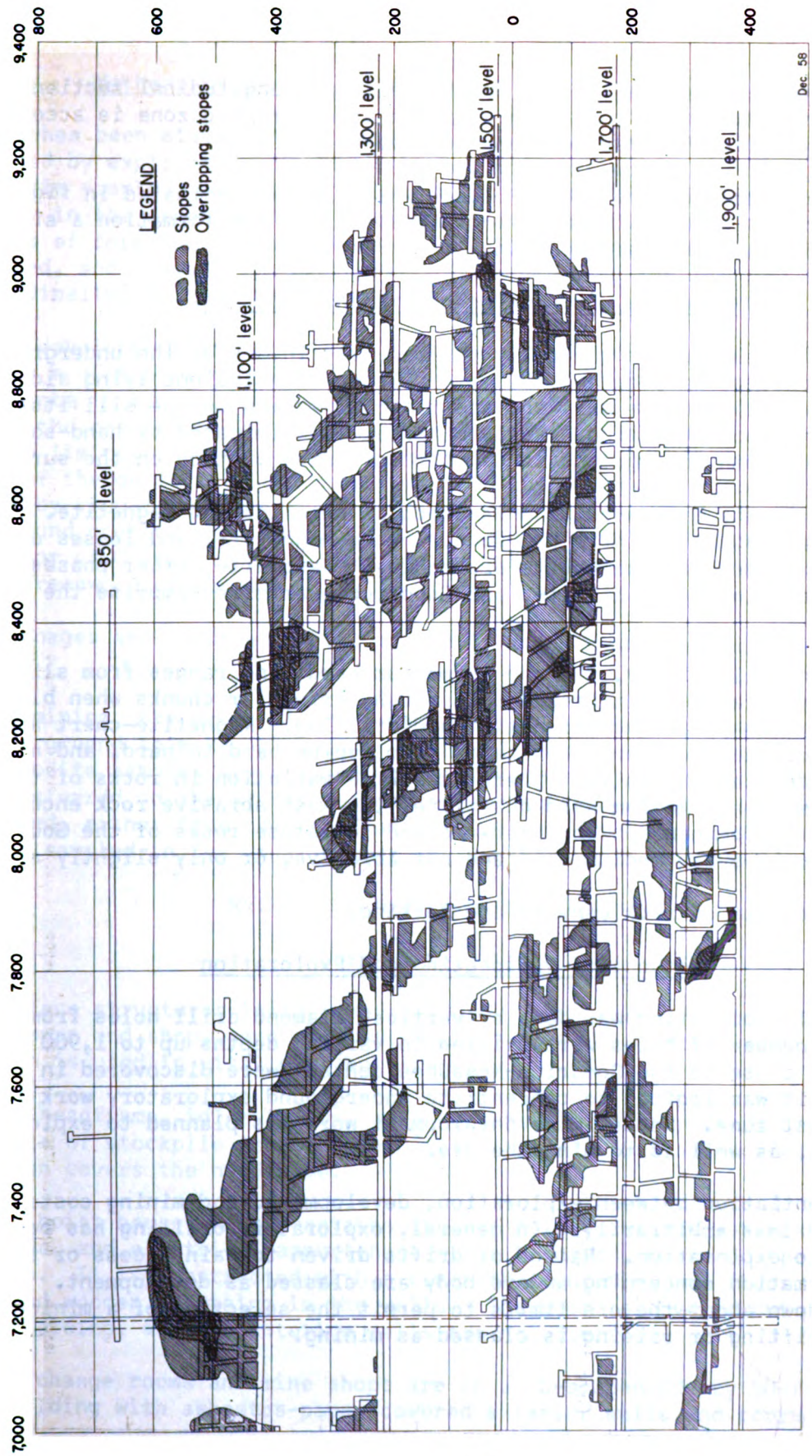

FIGURE 4. - East-West Longitudinal Section of Greenwood Mine, West of Coordinate 7,000 West.

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that the projections of the stopes on the vertical longitudinal section overlap in places. Mining in more than a single stratigraphic zone is accounted for, in part, by folding, as mentioned above.

The main Greenwood ore bodies plunge westerly, as indicated in figure 4. Some 10 miles westward on the main southern belt of iron formation a similar structure exists at the Champion mine.

Physical Properties of Ore and Wall Rock

Artificial support is generally not required in any of the underground openings. However, in stoping, the more siliceous inclusions lying alongside the hanging wall intrusive sill and the material making up the sill itself readily fall without blasting. Waste material is eliminated by hand-sorting to some extent both underground and in the screening station on the surface.

The ore in the Greenwood mine is specular hematite and magnetite. Irregular masses of magnetite-chert are found in the magnetite, and lenses of jaspilite occur in hematite-magnetite ore bodies. Jaspilite, other phases of iron formation, intrusive diorite, and Goodrich quartzite comprise the wall rocks.

Based on drillability, the ore is medium hard, and ranges from slightly to moderately abrasive. It breaks into rough, irregular chunks when blasted. Jaspilite is classed as exceptionally hard drilling. Magnetite-chert and other rocks of the iron formation range from medium hard to hard, and all types are moderately abrasive. There is a wide variation in rocks of the Goodrich formation. Medium-hard quartzite, the most abrasive rock encountered in the wall, is dominant. Conglomeratic and schistose rocks of the Goodrich and the intrusives are medium hard and not abrasive, or only slightly so.

Specific data on rock density are lacking.

Methods of Prospecting and Exploration

Original prospecting was done by vertical diamond drill holes from the surface. A number of holes were drilled to varying depths up to 1,900 feet. Ore deposits close to the Goodrich-Negaunee contact were discovered in this manner, and it was logical to concentrate underground exploratory work largely in the contact zone. Hence, mine development work was planned to explore the contact zone, as well as to mine the ore.

Differentiation between exploration, development, and mining costs is made more or less arbitrarily. In general, exploratory drilling has been chargeable to exploration. Raises or drifts driven to gain access or to obtain information concerning an ore body are classed as development. After enough is known about the ore limits to permit the selection of a mining plan, all other drifting or raising is classed as mining.

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Methods of Sampling and Estimating Tonnages and Values

It has been stated that information on what constitutes a minable ore body is gained by exploratory diamond drilling and development drifting and raising. Drill hole samples, as a rule, comprise both core and cuttings. However, core recovery in the Greenwood mine area has been practically 100 percent, and analyses of core samples only were made. Core was placed in storage boxes, inspected, and logged by a geologist. Core selected for analysis was split longitudinally, and a portion was sent to the chemical laboratory for analysis.

In development and mining work, broken ore is sampled as necessary. There is a distinction between sampling for estimation purposes and for grade maintenance in mining. As a matter of fact, because of the sharp delineation between the ore and rock, there is a minimum amount of sampling done to determine the limits of an ore body for estimation purposes. This is the responsibility of the geologist, and demarcation of ore limits in almost all instances is done by visual inspection. Ore limits are extended up to 50 feet beyond an underground opening or diamond drill hole traversing the ore zone. This limiting factor of 0 to 50 feet is used because of the small average size and shape of the Greenwood ore bodies.

Tonnages are computed on a basis of 10 cubic feet per long ton of ore in place.

In mining, the grade of ore is maintained by grab samples taken from each car underground to make up a composite sample for each shift. For comparison, the composite samples are obtained by grab samples from each carload of sized ore transferred on the stockpile landing during the same shift. When the ore is shipped, either from the headframe pockets or from the stockpiles, railroad cars are sampled in the usual manner in five-car units to compile cargo grades.

METHODS OF DEVELOPMENT AND MINING

Surface Facilities

Surface structures include hoist house, headframe and appurtenances, change house and shops, and mine office. Fireproof or fire-resistive construction is used in vital mine buildings.

The headframe, idler towers, skip hoppers, shipping pockets, and permanent bents of stockpile trestle are built of steel. Galvanized corrugated sheet iron covers the headframe.

The hoist house, which contains the one hoist, two compressors, two d.c. convertors, and electrical appurtenances, is L-shaped, 60 by 64 feet, and 23 feet high. It is constructed with a concrete foundation and floor, a wooden frame, and wooden sheathing in the walls. The roof is covered outside with asbestos siding, and the interior walls are not finished.

The change rooms and mine shops are in an L-shaped 80- by 50-foot wooden-frame building with asbestos-paper-covered exterior walls and corrugated sheet

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iron roof. Interior construction features dry wallboard and concrete floors. The building includes change and locker rooms, machine shop, carpenter shop, welding shop, drill steel shop, and lamproom with battery-charging racks. Miners' change room is equipped with overhead-hook-design hangers in both the clean-clothes and work-clothes room, and with shower units, Bradley wash fountain, laundry sinks, and toilet facilities. An office and changing facilities are provided for the mine captain and shift bosses.

Development

A vertical shaft was sunk in the hanging wall Goodrich quartzite. Stations were provided at the shaft for levels at the approximate vertical depth of 850 feet and at 200-foot intervals starting at the 1,100-foot level and continuing to the 1,900-foot level. The 850-foot level was not driven until 1957, when it was opened up for exploratory purposes. Crosscuts were driven south from the shaft stations on each level to the quartzite-iron formation contact. Main-level drifts were driven east and west along this contact. The hanging wall was found to be irregular, and as a result, the main-level drifts have no long straight runs.

As the main-level development progressed, the contact zone was explored by underground drilling, raises, and sublevel drifts. Relatively short horizontal holes were drilled by percussion drill and by diamond drill. Holes were drilled both normal to the bedding and laterally more or less with the strike.

After determining the limits of an ore body on a level, the general procedure was to explore to the upper limit by raises and to the lateral limits by sublevel drifting.

In searching for a downward extension of an ore body, which was developed or had been mined above a given level, diamond drill holes were used. In some cases such drilling showed that the ore did not extend to the next lower level. In such cases, that level was extended and a raise was driven to intercept the bottom of the ore body. Raise 870 on the 1,900-foot level at coordinate 8,700 is an example of this procedure. This raise was driven up to the 1,700-foot level for ventilation and access for further development.

The size of the ore body, its mining limits, and the mining method selected dictated the spacing of the sublevels and raises.

Three stoping methods are employed: Open stoping, longitudinal sublevel stoping, and longitudinal shrinkage stoping. These methods will be discussed in detail under appropriate headings.

Shaft Sinking and Shaft Stations

A cross section through the hanging-wall vertical shaft is shown in figure 5. The shaft was originally designed with five compartments to accommodate one cage, two skips, pipes and cables, and a ladderway. However, later an air-supply pipe was installed in the cage compartment, and two cages were hung under the skips.

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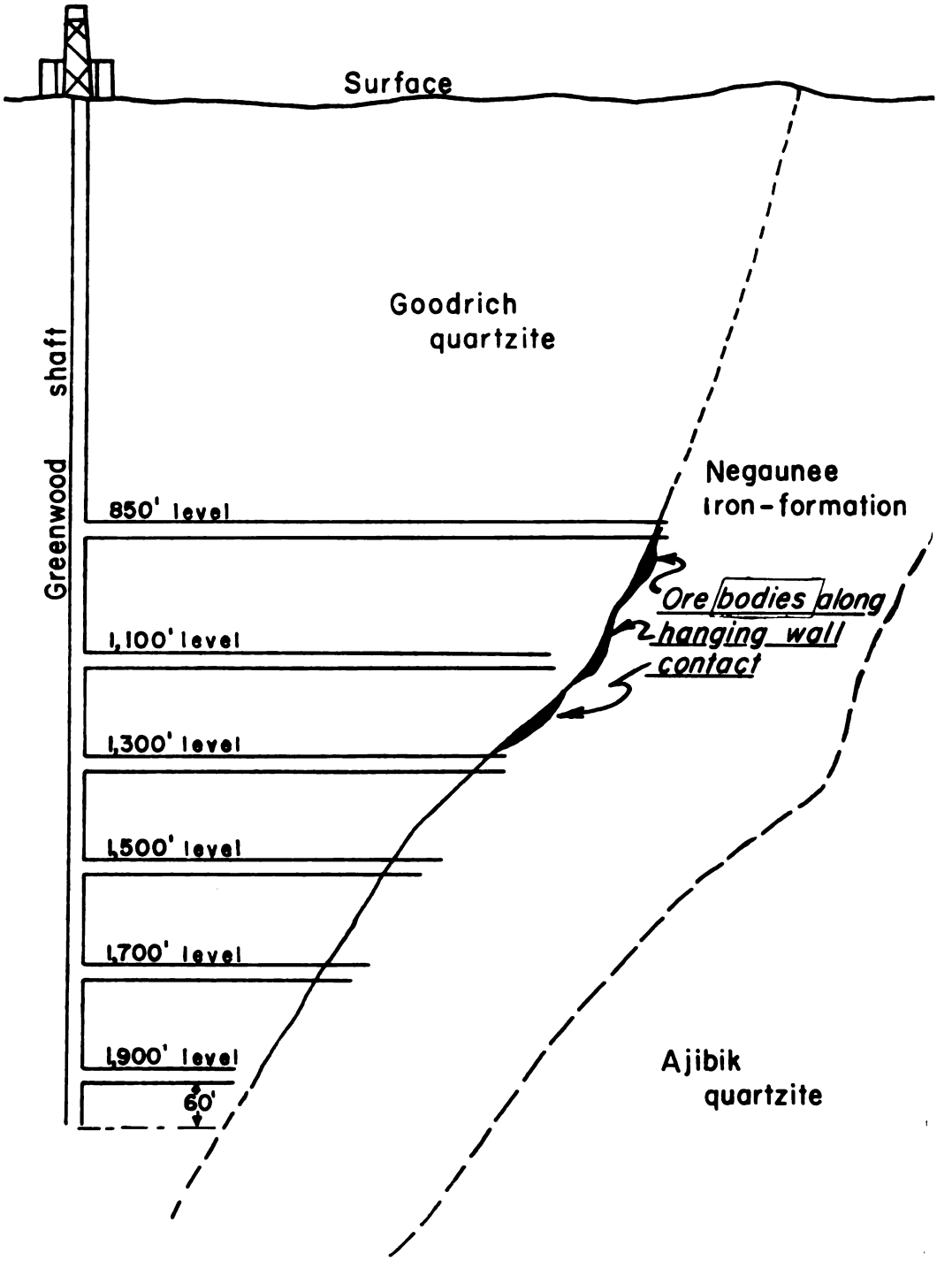

FIGURE 5. - General Section Looking East, Through Greenwood Mine.

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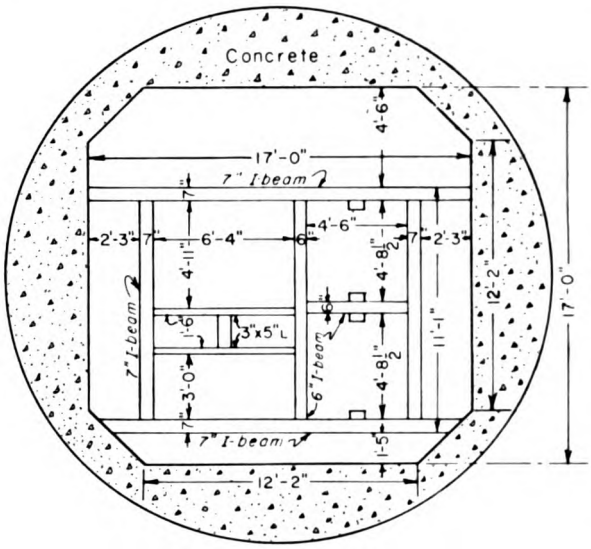
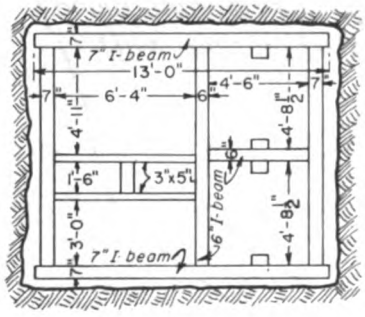
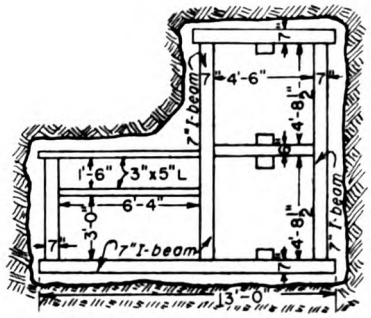


PLAN VIEW AT COLLAR
0'-105'



PLAN VIEW
105'-1,145'
and
1,348'-1,965'



PLAN VIEW
1,145'-1,348'

FIGURE 6. - Shaft Sections at Collar and Various Depths, Greenwood Mine.

Through glacial drift a circular reinforced-concrete caisson was sunk to ledge and sealed into bedrock. Inside, its design was square with beveled corners, 17 by 17 feet inside dimensions. Sinking was performed under air pressures up to a maximum of 45 p.s.i., and caisson control was modified by applied weights.

Shaft sets at 7-1/2-foot centers were installed in the caisson and in the rock section of the shaft. Figure 6 shows the shaft sections at various depths. The main members consist of 7-inch I-beam steel (fig. 7). The rock section was not lagged completely.

At the shaft station, a 12-inch grizzly is provided at the shaft pocket opening. All chunks over size are pulled off the grizzly into a trench beyond the shaft station and blockholed.

Required storage facilities vary on different levels.

A skiptender controls the mechanism regulating flow of material into the skip-loading measures and skips and signals the hoistman by an electric bell system.

Drifts and Crosscuts

Main-level drifts and crosscuts are driven commonly 9 by 9 feet in size and do not require timber support.

Figure 8 illustrates a typical drift round and rotation of blasting.

Drilling and Drilling Equipment

Drilling Equipment

All drills are equipped for wet drilling; the water pressure varies from 40 to 86 pounds, with the lower limit about average. Gardner-Denver line oilers are provided 8 to 12 feet from the machine. The average air pressure is 90 pounds.

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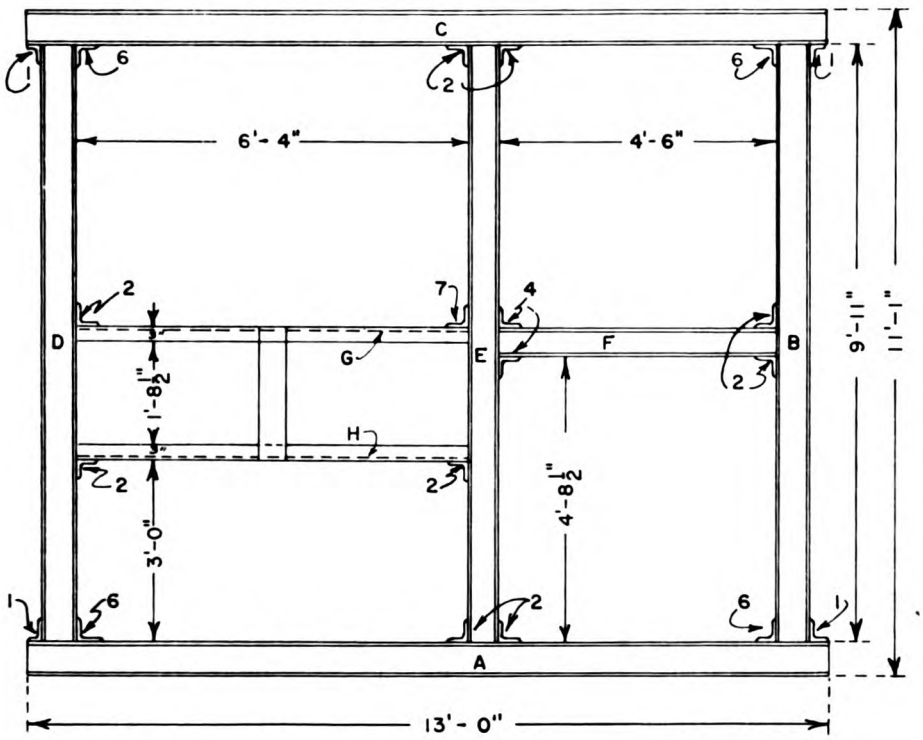

REGULAR SET

LIST OF MATERIALS

No.	Description	Mark	Size	Length	Weight	Remarks
27	I-Beams	A	7"	13'-0"	15.3 lb.	
27	"	B	7"	9'-10½"	15.3 lb.	
27	"	C	7"	13'-0"	15.3 lb.	
27	"	D	7"	9'-10½"	15.3 lb.	
26	"	E	6"	9'-10½"	14.75 lb.	
26	"	F	6"	4'-5½"	12.5 lb.	
1	"	I	6"	11'-3½"	14.75 lb.	
4	"	J	6"	14'-11¼"	14.75 lb.	
3	"		10"	14'-0"	25.4 lb.	Bearers
3	"		10"	13'-0"	25.4 lb.	Bearers
3	"		10"	15'-0"	25.4 lb.	Bearers
3	"		10"	18'-0"	25.4 lb.	Pocket, 4th. level
1	"		10"	16'-0"	25.4 lb.	Pocket, 4th. level
52	Angles	G & H	5"x3"x5/16"	6'-3½"		
130	"	S	4"x4"x3/8"	7'-1¼"		Stuttles
6	"	L S	4"x4"x3/8"	14'-7¼"		Long stuttles
130	"	6 & 7	4"x4"x3/8"	1'-6¾"		
300	"	2 & 4	4"x4"x3/8"	0'-4¾"		
110	"	1	4"x3"x3/8"	0'-4¾"		
26	Flats		5"x½"	2'-2½"		

FIGURE 7. - Shaft Set Detail and List of Materials.

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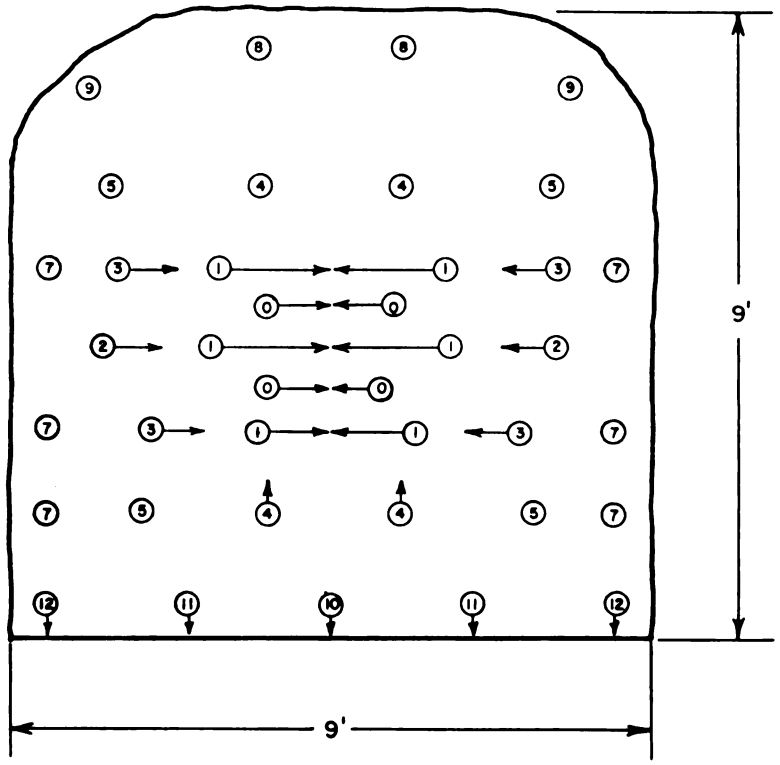

Note:
All holes drilled 10' deep.

FIGURE 8. - Typical Drift Round of Greenwood Mine.

Table 2 gives details on type of drilling equipment used for specific operations.

In general, the use of a post or rigid-mounted air-bar feed mounting is much easier on bits in the hard ground encountered in this mine. This type of mounting maintains an even pressure on the bit, thus giving better cutting action. It eliminates the smashing of bits due to pounding.

Drill Steel Heat Treatment

The hard ore and rock types at the mine, the hardness of which ranges upward from about 6 on Mohs' mineral-hardness scale, may be classed as medium to exceptionally hard drilling ground.

Dating back to the practice of forging bits on steel, followed by use of conventional steel detachable bits before the advent of tungsten carbide-insert bits, a well-equipped shop was installed for sharpening and heat-treating bits and drill steel. Experienced blacksmiths and mechanics were developed.

The drill steel shop equipment includes: IR No. 500 drill steel cutter, IR oil-fired furnace for heating, IR No. 50 sharpener for forging, Toledo 2-inch high-speed threading machine, IR J-2 oil-fired furnace for heat treating, and one salt bath (16-rod capacity) for tempering.

Drill Steel

Bethlehem ultraalloy drill steel is used in 1-inch and 1-1/4-inch hexagonal sections. About 97 percent of the steel used is 1-inch size. Drill steel shanks are collared, and lengths from 1-1/2 to 10 feet are provided.

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Although changes in the upper length range are used more frequently, more breakage is noticed in the shorter lengths of drill steel. This may be due to fatigue as shorter drill rods are made from previously broken or discarded longer rods. The most common reason for drill steel failure is that of the threads wearing out, not strippage. The relative frequency of drill-rod failures are:

	Percent
Thread wear.....	78
Button breakage.....	3
Shank.....	2
Metallurgical notch zone...	2
Other.....	15

TABLE 2. - Type of drilling equipment for specific operations

Operation	Machine size, inches	Type of Mounting	Bit diameter, inches	Steel section	Depth of round, feet
Drifting.....	3	Jumbo, air-bar feed.	1-5/8 1-1/2	1-in. hexagonal.	9
Stoping:					
85 percent..	2-5/8	Post, air-bar feed.	1-1/2	1-in. hexagonal.	10
15 percent..	2-5/8	Jackleg.	1-1/2	1-in. hexagonal.	10
Raising.....	3-1/8	Stoper leg.	1-1/2	1-in. hexagonal.	6
Long-hole.....	4-1/2	Post, screw feed.	2-1/2 3-1/2	1-1/4-in. hexagonal.	80
Prospecting...	Diamond drill	Post, screw feed.	EX	1-5/16-in. round.	200

Drill Bits

Tungsten carbide insert bits are used exclusively in blasthole drilling in the Greenwood mine. The hardness of cemented tungsten carbide compositions has been classed as ranging from 85 to 93 Rockwell A, which corresponds to 67 to 82 Rockwell C, and to 9.0 to 9.2 on Mohs' mineral-hardness scale. Sizes of bits used are:

	Percent
1-1/2-inch.....	80.3
1-5/8-inch.....	16.8
2-3/4-inch, 3-inch, 3-1/2-inch	2.9

The cross bit is the standard design; other types have been tried. Thread connection is provided, and in most cases bits are reused until threads wear out.

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Drilling Tests

Table 3 gives penetration data for different machines and type of rocks:

TABLE 3. - Penetration data for different machines and types of rock

Type of Drill	Piston diameter, inches	Bit diameter, inches	Air pressure, pounds	Average penetration, inches per minute	Percent of total	Type of rock
Gardner-Denver 79 Drifter, mounted on Joy jumbo....	3	1-5/8 1-1/2	90	6	100	Jaspilite.
Cleveland HC-10 Drifter, post mounted..	2-5/8	1-1/2	90	7.2	100	Magnetite and specular hematite.
Ingersoll Rand J-50 Jackleg..	2-5/8	1-1/2	90	7.5	100	Specular hematite.
Gardner-Denver R104 Stoper..	3-1/8	1-1/2	90	5.7 3.0		Specular hematite. Jaspilite

Raises

The ore in the Greenwood mine is specular hematite and magnetite. It is fairly hard and abrasive, but fractures well when blasted. Also, the ore is hard enough to retain its shape without cribbing for raises.

Methods followed in raising are:

1. Conventional raising by short rounds.

2. Drilling a single 3-inch-diameter long hole between levels to serve as the centerline for the raise and a "buster hole" for the blast and also to provide a means for hoisting all staging and drilling materials to the working face. Hoisting is done by a tugger hoist mounted above the proposed raise with the hoisting cable being operated through the long pilot hole.

3. Using a long-hole machine to drill out a raise completely from either top or bottom. The holes are loaded and blasted from the top. This method is described in detail below:

Driving Raises by the Long-Hole Method

Experimental raising by this method in the Inland Steel Greenwood mine on the Marquette range in Michigan shows favorable costs per foot of raise and safer working conditions.

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Experience gained in blasting a hole through a narrow floor pillar being mined by long-hole drilling was a forerunner to raising by this method. To eliminate the danger of breaking the ore into large pieces and leaving the blasted mass hung up over the open stope below, it was decided to load a charge of explosives in the bottoms of the holes to break small portions of the ore to a stope below. By repeated blasting, an irregular hole was broken through, thus developing a method of blasting small portions of long holes grouped closely together.

The first raise by the long-hole method was completed at the Greenwood mine in July 1957. It was a 40-foot, single-compartment, unsupported raise. The drilling pattern decided for the first raise was a burn-cut round consisting of a center relief hole with four holes around it, two at 9 inches and two at 12 inches from the center of the raise, and six outside holes on the perimeter of a 4-foot circle. A 4-1/2-inch percussion drill was set up on the sublevel at the bottom of the proposed raise, and eleven 3-inch diameter holes were drilled. Extreme care was taken in the alinement of the holes and in repeated checking during drilling operations to keep them as nearly parallel as possible.

When the drilling was completed, the pattern was not the same as the starting pattern, but none of the holes deviated more than 12 inches from its intended breakthrough. Three types of bits, a chisel point, an X-bit, and a cross bit, were used for experimental purposes in drilling the holes. Results showed that the cross bit drilled the straightest hole in this type of ore, and it was used thereafter for drilling in raises where the holes should be as nearly parallel to the centerline of the raise as possible.

In blasting this raise, all equipment was removed from the bottom, and the explosives charges were loaded into the holes from the top of the proposed raise. First, the bottom of each hole had to be plugged by means of a wooden plug attached to a sash cord. The plug was raised and lowered until the bottom of the hole was determined. Then the plug was wrapped with paper and pulled into place, the paper served to bind it, and a few inches of dirt was tamped on top of the plug. The holes were loaded with Gelamite 1X-60 in 2-1/2- by 16-inch and 2- by 16-inch cartridges, primed with Hercules NoVent delay electric blasting caps. Care was taken to keep the top of the dynamite charges in a plane normal to the raise centerline to maintain as clean a cut as possible. From 4 to 6 inches of stemming was used on top of the column of explosives in each hole.

Five rounds were fired to bring the raise up to within 2 feet of the upper level. The first and longest round blasted was 12 feet. This produced some overbreak around the raise, which was caused by propagation probably due to a fracture in the ore. The charges in the remaining blasts detonated in proper order. The second blast was reduced to 4 feet, the third to 7 feet, the fourth to 8 feet, and the fifth to 7 feet. All broke fairly clean to the tops of the columns of explosives. The remaining 2 feet was drilled with small jackhammer holes and blasted.

The explosives loading ratio was 25 pounds per 1 foot of raise. In the overall cost per foot of raise, the long-hole method compared favorably with

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methods used previously. In the future, smaller diameter holes will be drilled to speed up drilling and reduce the explosives loading ratio per foot of raise. The ore in this raise was pulverized due to loading a large volume of powder required in the 3-inch-diameter holes. The initial blasts will be reduced in length to keep the overbreak to a minimum and to minimize the chances of propagation in fractured ground. The length of the succeeding cuts will be increased as the raise is advanced.

Mining

The mining methods used in underground mining of hard ore on the Marquette range are listed below. Stoping methods are in accord with the Bureau of Mines classification based upon method of support. Notations on stoping practices are added to indicate details of stoping procedure for comparison purposes in enumerating the conditions that govern choice of methods.

Mining Methods Used in Underground Hard-Ore Mines on the Marquette Range

A. Stopes naturally supported: Open stopes.
   1. Open stopes without pillar support.
      a. Open stoping in small ore bodies.
      b. Sublevel stoping.
         Longitudinal, underhand stoping.
   2. Open stopes with pillar support.
      a. Regular pillar arrangement.
         Transverse, underhand, sublevel stoping.

B. Stopes artificially supported.
   1. Shrinkage stoping.
      a. Without pillars.
         Longitudinal, shrinkage stoping.

Choice of mining methods at the Greenwood mine has been influenced largely by size of ore bodies, economic factors, such as development cost and necessity of securing as large a percentage in ore extraction as possible, and physical conditions. In the last 2 years, another economic factor has developed: that of maintaining a steady mine production at the time when reserves, particularly in larger ore bodies, were dwindling. This was one factor in the large increase percentagewise of ore mined by sublevel rather than shrinkage stoping. The advantage of having less broken ore tied up in stopes partially compensated for the increased cost of scraping a larger percentage of ore mined.

The physical characteristics of the ores and associated wall rocks at the Greenwood mine are similar to those prevailing on the western Marquette range. The iron formation has been altered rather extensively by metamorphism but only slightly by processes of secondary oxidation, leaching, and replacement that produced soft-ore concentration elsewhere on the range. As a result, both ores and associated wall rocks are hard and, being relatively unoxidized, dense. From a mining standpoint, the formations may be said to be firm, except for schistosity adjacent to the sills. Where this structure has been

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developed it tends to cause unexpected falling in slabs, under conditions of lack of support, due to vibrations set up in blasting operations in the stope. In some of the larger stopes in the Greenwood mine, a thin sill has been mentioned as occurring between the Negaunee iron formation and the overlying Goodrich formation.

In order to stope close to the sill and assure as large a recovery of ore as possible without excessive dilution by waste, shrinkage stoping has been selected, heretofore, as the best method of mining to meet conditions outlined above and maintain safe working places. However, in the lower levels schistosity adjacent to the sill along the Goodrich contact has worsened, causing excessive dilution in some areas. This condition has influenced the change to sublevel in preference to shrinkage stoping.

Sublevel stoping in open stopes without pillar support is the mining method used at the Greenwood, where the walls and back are firm enough to stand during the period of ore extraction in the entire stope. Usually the two walls are oxidized iron formation of the jaspilite type, commonly called hard-ore jasper. Stopes also have a hanging wall of the schistose rock mentioned above. Generally, the ore bodies are small (50 to 100 feet long and up to 40 feet wide). Some ore bodies of greater magnitude are mined presently.

Open stoping in small ore bodies is carried on, and physical characteristics of ore and wall rock are similar to those adaptable to sublevel stoping.

Open Stoping

Open stoping in the Greenwood mine is employed to mine small ore bodies, ore chimneys, and ore offshoots from the larger ore bodies.

The larger of these small ore bodies may be long enough to require two raises, one of which is located near each end of the ore body. A chute is built in one raise, and the other is maintained as a manway. Raises are continued to the top of the ore or upper limit of the proposed stope where ore extends to the level above. In the latter case, the manway raise is holed through to the level above. Starting at the chute raise at the top of the ore body, or upper limit of proposed stope, the stope is opened the full width of the ore body. Successive horizontal slices 8 and 10 feet high are opened up from the chute raise and carried the length of the stope.

Ore chimneys extending from one level to the next higher one have in a few cases been mined by utilizing a single raise for travelway and ore pass. Miners gained access to the stope from the level above, and ore was scraped into the same raise and transferred to the level below. In several instances, small ore offshoots have been mined by driving an inclined opening upwards on a slope of approximately 40°. Overhand stoping was the practice, and only enough ore was pulled away to make working room. The ore had to be scraped into a chute or loaded on the haulage level by an Eimco loader.

Some floor pillars on main levels have been mined with long-blasthole practices.

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Most of the ore mined in this category is produced by underhand open stoping, and this term has local usage in designating the ore so mined.

Sublevel Stoping

Sublevel stoping is employed in mining longitudinal underhand stopes. As has been noted, the ore bodies mined by this method are relatively small. The initial development work usually consists of two raises, one near each end of the ore body. If required, additional chute raises are driven up from the main level to limit the scraping distance to approximately 100 feet. A chute is built in every raise except the one maintained as a manway. Raises are continued to the top of the ore or upper limit of the proposed stope where ore extends to the level above. In the latter case, the manway raise is holed through to the level above. The raises are connected across the top of the ore body, or at the upper limit of proposed stope, and on successive sublevels by drifts. These sublevel drifts are 30 to 40 feet apart vertically, and are driven the full width of the ore body. They are started at the chute raise and driven to the manway.

At present, in one sublevel stope, a floor pillar on the level above is being mined above the top sublevel drift. Usually after the top sublevel drift is driven, the next lower sublevel drift is driven the length of the ore body. The ore in the back of this drift is mined by drilling upper holes in successive rounds working back towards the chute raise. Broken ore is scraped into the chute raise.

The stope is carried down in successive stages; hence, longitudinal, underhand sublevel stoping may be used in referring to the mining method. However, mining operations differ so radically from sublevel stoping as carried on at the soft-ore Morris mine that the broader term open stoping has been applied locally to the method of mining.

Shrinkage Stoping

Longitudinal shrinkage stopes have a length of up to 400 feet, measured along the strike of the ore body, and are mined from the sill floor 25 feet or more above the level to within 35 to 40 feet of the level above, or to the top of the ore in ore bodies that pinch to an unminable width.

Preliminary development of shrinkage stopes by two raises, one at each end, has been described in the section on Development. Both raises may extend from the haulage level to the level above, and one is maintained as a service raise or manway. Sublevel drifts are spaced at vertical intervals dependent upon development of minable ore in the stope area, and are used for access to the stope. Stopes are silled about 25 feet above the rail of the level. Silling is begun by connecting the manway with an adjacent raise by a sublevel drift and belling out the top of the raise to be used for broken ore disposal during the initial stage of silling. The rest of the raises in a stope are driven at 25-foot centers and belled out one at a time as they are needed to keep pace with the silling. Silling is extended the width of the ore body by means of slashing from the first sublevel drift, and eventually the entire stope area is silled out.

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The manway provides access to the stope and is the starting point for mining each horizontal slice above the sill. The successive slices are opened by drilling in the back at the manway and crosscutting the width of the stope 5 to 8 feet high. From this slot, the stope back is drilled in slightly inclined upper holes in 8- to 10-foot rounds and blasted. Because of a sill, and/or slaty member of the Goodrich formation along the contact, drilling and blasting close to the hanging wall is done sparingly.

The stoping practice is overhand, and only enough ore is drawn through the chutes to provide working room.

Mining Costs

Mining costs in dollars are not available for publication. Instead, a percentage breakdown of direct mining costs is given in table 4, and a breakdown of general expenses is shown in table 5. In the latter, percentage breakdown is given of total costs f.o.b. railroad cars at the mine, exclusive of depletion and amortization.

Table 6 is a summary of costs in units of labor, power, and supplies, together with performance data. These data may be useful in measuring the efficiency of operations in sublevel stoping under the special conditions imposed at this mine.

Two-thirds of the ore production was gained by sublevel stoping. Breaking operations in sublevel stoping and shrinkage stoping at this mine are carried on quite similarly, and such costs in both methods are practically the same. The saving in gravity transfer of ore in shrinkage stoping, relative to scraping in sublevel stoping, is offset by higher costs in the small amount of open stoping carried on.

Hence, for purposes of comparison, data submitted in table 6 may be used for sublevel stoping operations on a 100-percent basis.

The amount of rock hoisted during 1957 was greater than that hoisted normally. Much of it came from the 850-foot level and was chargeable to exploration and other deferred costs. Therefore, costs and performance data in table 6 do not include the rock work.

Underground Transportation

Transportation underground on main haulage levels is by means of electric locomotives and cars.

Electric-trolley locomotives, weighing 3 to 4 tons, are used in the underground haulage system. They are operated on 250-volt d.c. circuit. The converter for this circuit is in the engine room on the surface. Minor maintenance may be done on locomotives underground; however, major repairs are done on the surface. A locomotive must be hoisted and lowered in the main shaft by being suspended beneath the cage.

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TABLE 4. - Cost distribution for mining operations, January 1 to December 31, 1957: A breakdown for specific items in percentage of total direct mining costs

	Percent of total direct mining costs		
	Labor	Power and supplies	Total
Operating costs:			
Development	7.01	3.80	10.81
Mining (stoping)	26.49	9.81	36.30
Haulage (tramming)	10.87	1.13	12.00
Hoisting	4.09	1.97	6.06
Pumping	.19	.42	.61
Mine ventilating	.37	.48	.85
Supply handling	.63	.06	.69
Supervision	5.96	--	5.96
Engineering	1.40	--	1.40
Safety	.19	.31	.50
Crushing and screening	.34	--	.34
Loading direct	.22	--	.22
Stockpiling	1.40	.41	1.81
Loading from stockpile	.15	.06	.21
Office and warehouse	2.52	.25	2.77
Buildings and grounds	.06	.63	.69
Dryhouse, watchmen, lampmen	3.44	.09	3.53
Laboratory and sampling	.10	.25	.35
Sundries, miscellaneous expense	.14	.29	.43
Total	65.57	19.96	85.53
Repairs and maintenance costs:			
Drifts, raises, and auxiliary shafts	.40	.15	.55
Hoisting shaft	.42	.05	.47
Mining equipment	2.23	2.41	4.64
Tramming equipment and tracks	1.61	1.94	3.55
Hoisting equipment	.59	.18	.77
Headframe equipment	.23	.56	.79
Stockpiling facilities and equipment	.58	.48	1.06
Mine ventilating equipment	.42	.23	.65
Pumps	.25	.09	.34
Power shovels and cranes	.36	.46	.82
Automobiles, trucks, and tractors	.02	.02	.04
Power, light, and signal systems	.31	.02	.33
Buildings and grounds	.04	.01	.05
Other equipment	.16	.25	.41
Total	7.62	6.85	14.47
Total direct mining costs	73.19	26.81	100.00

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TABLE 5. - Cost distribution for mining operations, January 1 to December 31, 1957: Direct mining costs and a breakdown for general expenses in percentage of total costs

	Percent total general expenses	Percent total costs
Total direct mining cost.....	------	78.66
General expenses:		
Vacation and holiday expense.....	22.16	
Current pension cost.....	9.76	
Employees group insurance.....	5.51	
Supplemental unemployment.....	3.28	
General insurance.....	1.69	
Accident insurance.....	4.73	
Sundry Chicago office charges.....	.06	
Social Security taxes.....	10.59	
Real estate and personal property taxes.....	9.83	
Miscellaneous taxes.....	.14	
Royalty (mine).....	13.39	
Depreciation.....	6.21	
Ishpeming general office.....	12.65	
Subtotal.....	100.00	21.34
Total cost (exclusive of depletion and amortization).....		100.00

Two types of cars are used: Rocker-type, round-bottom, 65-cubic-foot cars, which are dumped manually, and 98-cubic-foot flat-bottom cars, box-hinged along one side to the frame. These are called roll-over cars, and the box of the car is dumped by activating an air cylinder.

Main haulageway grades of one-half percent in favor of loads is the practice. Forty-pound rails with welded bonds at 24-inch gage are laid on 5-inch wooden ties spaced at 18-inch centers. Ballast consists of fine rock waste. Cast steel frogs, machined switch points, and switch throwers with enclosed springs are used.

Portable storage-battery lights are installed on the end cars of trains. Hand-operated signal systems are used.

Hoisting

A single-drum hoist is used for both cage and skip hoisting. The hoist is operated by a geared induction motor rated at 600 hp.

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TABLE 6. - Summary of costs in units of labor, power, and supplies

Mine: Green wood — Period covered: January 1 to December 31, 1957

Mining methods employed:
- Shrinkage: 25 percent
- Sublevel stoping: 67 percent
- Open stoping: 8 percent

Ore hoisted during period: 62,384 long tons
Rock hoisted during period: 4,688 long tons

Labor:		
Day labor, underground and surface, chargeable to mining.....man hours	104,616	
Day labor, underground and surface, chargeable to mining, per long ton of ore.....do....		1.68
Supervision, engineering office.....do....	10,280	
Supervision, engineering office, per long ton or ore.....do....		.16
Subtotal.....do....	114,896	
subtotal, per long ton of ore.....do....		1.84
Production per man-shift:		
Day labor, underground and surface.....tons per man-shift		4.77
Total labor.....do....		4.34
Power and supplies:		
Explosives.....lb. per long ton of ore		1.45
Kind and grade. 50 percent each: Gelatin Extra - 80 percent; Gelamite 1X - 60 percent		
Timber.....board feet	37,830	
Power:		
Air compression.. 59.1 percent ..kw.-hr. per long ton of ore		10.9
Tramming..... 12.3 ...do.. .....do....		2.3
Hoisting..... 12.8 ...do.. .....do....		2.3
Stockpiling..... 7.4 ...do.. .....do....		1.4
Pumping..... 7.4 ...do.. .....do....		1.4
Surface, lighting shop..... 1.0 ...do.. .....do....		.2
Total power...100.0 ...do.. .....do....		18.5
Analysis of direct mining cost:		
Labor.....Percent of total direct mining cost		73.2
Supplies.....do....		12.6
Power.....do....		5.6
Fuel.....do....		1.1
Explosives.....do....		6.4
Timber.....do....		.7
Miscellaneous expenses.....do....		.4
Total.....do....		100.0

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The hoist is equipped with speed control and overwind-prevention devices.

The hoist drum has a 9-foot diameter and an 8-foot face and is grooved for 1-3/8-inch, 6 by 25, preformed hoisting rope. An overlap is required.

Skips are self-dumping, generally know as the Kimberly type, and have safety guides to prevent tipping in the shaft. Skip capacity is 102 cubic feet. Cages are hung below the skips.

Cleaning Shaft Spillage. - Formerly, spillage in the shaft was cleaned up by handmucking. A bucket was hung by a cable underneath the cage. The bucket was lowered to the bottom of the shaft, and a crew of four miners mucked by hand into the bucket. When the bucket was filled, it was hoisted to the 1,900-foot level and swung out of the shaft over the pocket and dumped into the pocket. This was a slow and costly procedure which had to be done on a weekend. Two crews of four men worked two shifts on a weekend about once every 2 months.

The arrangement utilized in cleaning shaft spillage is shown in figure 9. The present system utilizes an old Bucyrus shaft mucker, which consists of a hydraulic clamshell bucket with remote control. A hinged door was installed in the shaft and is moved by means of a single-drum air tugger. Another air tugger is used to hoist the bucket. All equipment, the two air tuggers, and a hydraulic pump and controls are located on the same platform and are operated by one man (fig. 9).

The clamshell bucket is dropped to the shaft bottom for a load and is hoisted up to the hinged chute. The chute is swung open to let the bucket pass up through it. As soon as the bucket is clear of the chute, the chute is dropped back and in this position acts as a slide. The bucket is opened, and the load falls on the chute and from there runs into the skip.

Under the present system, the spillage can be cleaned out in 2 hours once every 2 weeks.

Communications. - Telephone service is provided to the mine through the public telephone exchange.

Voice communication between facilities on the surface and between various stations in the mine, particularly between hoistman and shaft stations, is effected by means of sound-powered phone systems.

Screening, Shipping, and Stockpiling

The skips dump the ore in the headframe into a common bin, from which it is drawn to a pan conveyor and transferred to a double-deck vibrating screen. Screening is required to size the ore for shipment, and/or for stockpiling, in three sizes, designated by grade names: Senior, 12-inch plus 3-inch; junior, 3-inch plus 3/4-inch; and third, minus-3/4-inch.

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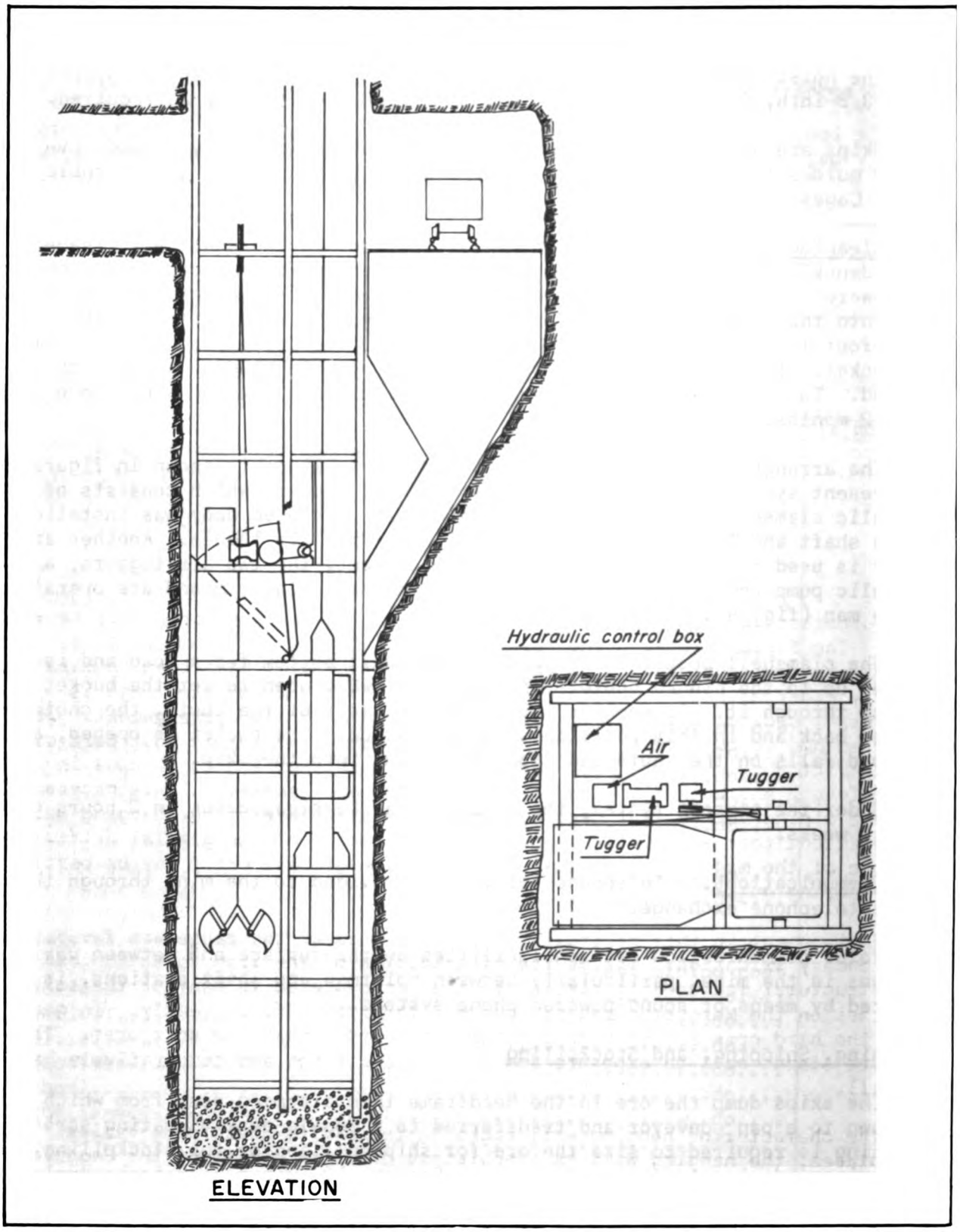

FIGURE 9. - Shaft Cleaning Setup, Greenwood Mine, Marquette County, Mich.

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The minus-3/4-inch ore, which approximates 20 percent of the mine product, is mixed at lake docks with soft ores from other mines for shipment to the blast furnaces. Ore in the other two sizes is shipped by rail to Escanaba, and thence by boat to the company steel plants. Junior-grade ore is dumped into the boats first to protect the hull against damage in loading the larger lumps. The two sizes (senior and junior grades) thus mixed constitute lump ore, which is used in the open-hearth furnaces for the processing of steel. Lump ore consequently is premium priced.

Kinds of ore produced in 1957 were:

	Long tons
Senior (12-inch plus 3-inch).....	27,757
Junior (3-inch plus 3/4-inch).....	21,483
Third (Minus-3/4-inch).....	13,144
Total.....	62,384

The sized ore is stockpiled, or loaded directly into railroad cars, in separate sizes. In stockpiling, a rocker-type car is transferred by a 4-ton electric-trolley locomotive.

Comparison of Different Methods Used in District

Mining Methods in Hard-Ore Mines

Comparison of different methods used in mining the hard ores will be made first. The factors influencing selection of mining methods and practices in open stoping and shrinkage stoping at the Greenwood mine have been enumerated. The only other method used in mining hard ores on the Marquette range is transverse, underhand sublevel stoping with regular pillar arrangement. This mining method is used on the north limb of the synclinorium in that part of the district where the ore bodies are both much thicker and continuous in strike length and both hard- and soft-ore mines are located. It is necessary to use a mining method that does not involve disturbance of the hanging wall to the extent that eventually might cause subsidence of the glacial drift. Here one of the major mining hazards is that the glacial drift may be partly water-bearing quicksand.

Environment in this centrally located portion of the range was favorable to secondary oxidation. The degree of oxidation of the iron formation and many structural features is similar to that encountered in many of the soft-ore mines on the Marquette range; however, the ores differ greatly. In general. the hard ores are of higher metamorphic order than the soft ores. The hard ore stands well on exposure and is firm and tough and comparatively hard to drill.

The character of hanging-wall rocks in the Cliffs-Shaft mine varies. In most places, the hanging wall is a schistose or slaty member of the Goodrich formation. Overlying this slaty member, which is seldom over 15 feet thick and usually much less, there is a strong, hard quartzite. Lenses of slaty iron formation may also occur in the hanging wall, and when altered to paint rock will slack on exposure to air. The schistose or slaty members of the

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Goodrich will loosen when exposed unsupported. Where the hanging wall is one of these formations, 8 to 15 feet of ore is left for support in the stope back. The footwall is jaspilite or an altered intrusive sill. The jaspilite stands well, but the intrusive occasionally gives trouble, especially where it lies at a steep angle or has been sheared by faulting.

This mine has the only hard-ore deposit on the range that is large enough to be mined by methods similar to those employed in mining soft and medium iron ores in comparable-sized deposits on the Marquette and other ranges in the Lake Superior district.

Mining Methods in Soft-Ore Mines

Briefly, we will mention the factors influencing selection of methods in mining soft hematite ores in the so-called soft-ore mines. The significant feature of the soft ores is volume-for-volume replacement. These ores are characterized by little or no slumping, and by an increase in the porosity, which measures the intensity of oxidation, chert removal, and/or replacement.

The Negaunee iron formation is the principal host rock for soft ore bodies. Structural control is provided by basic intrusives occurring in large sills and masses and in narrow dikes within the iron formation. Folding and faulting have set up closely spaced intersecting joints and related fractures, particularly in the iron formation, and in some instances have developed schistose structure in associated rock formations, especially the intrusive rocks.

Therefore, the Negaunee iron formation adjacent to a soft ore body is almost invariably oxidized, partially leached and/or replaced, and often badly fractured. Many of the intrusive rocks have been metamorphosed so severely that they, as well as certain types of sedimentary rock formation, have been classified as paint rock, slate, or schist. There is a wide variation in effective alteration processes, with a corresponding variation in density, soundness, and structure. Moderately sized openings standing well for varying intervals will cave, and the caved product will be roughly coarse rubble. These factors may be qualified by stating that size, shape, and position within the iron formation, together with any contained intrusives, dictate the mining method to be used. Position within the iron formation includes stratigraphic location as well as altitude.

Block caving is employed on large blocks of clean soft ores having a reasonable height.

Sublevel caving is used where the ore and associated rock have been fractured enough to be classified as heavy ground, or where the ore is contaminated by dikes. This method of mining is adapted primarily to dipping and pitching irregular ore bodies not large enough for block caving. Sublevel caving largely, if not entirely, replaced top slicing after the supply of relatively cheap local timber was exhausted. This method also supersedes sublevel stoping under the following conditions.

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Sublevel stoping is used in smaller, narrower, steeply dipping or vertical lenses of ore, where the walls and capping are strong and stand well during the extraction period at least, but may be dangerous to work under when undercut. As a rule, such ore bodies occur nearer the footwall than the large ore bodies, the size of which generally dictates mining by other methods. Sublevel stoping is also used in mining the upper portions of the larger ore bodies until contamination by lean ore or rock reduces the grade of ore; when this occurs, the balance of the ore body is mined generally by sublevel caving.

Sublevel stoping and sublevel caving may be modified by long-hole drilling practice, which entails an increase in sublevel interval up to 50 feet maximum.

Ventilation and Air Conditioning

To ventilate the mine a 40,000-c.f.m. fan is installed on the surface, and air is carried underground in a 4- by 4-foot steel tube, which conveys the fresh-air current out on the 850-foot level.

The fresh-air courses extend down through various raises and levels to the 1,900-foot level, and are controlled by wooden bulkheads. From the 1,900-foot level, the return air current is diverted into the hoisting compartments of the shaft, which are utilized as an upcast to surface.

Air doors, operated by air cylinders, are placed in main-level drifts to prevent air from short circuiting, except on the 1,900-foot level as noted.

Auxiliary fans ranging in size from 5,000 to 15,000 c.f.m. are set up to ventilate mining places which are off the main air courses.

Heat is necessary to keep ice from building up in the air duct. A heating plant is operated on the surface during winter months to maintain temperature of the fresh-air current above freezing. The system is thermostatically controlled. The heating unit is a stoker-fired boiler operating under low pressure.

Mine Drainage

The accumulated flow of all ground water coming into the Greenwood mine workings is small. The amount pumped to the surface is approximately 100 gallons per minute.

Water is collected in ditches on main levels and flows to the shaft, where it runs into a sump on each level.

Sump capacities are as follows:

	Capacity, gallons
Main level:	
1,100-foot.....	40,000
1,300-foot.....	28,000
1,500 foot.....	25,000
1,700 foot.....	25,000
1,900 foot.....	25,000

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Pumps on various levels are:

1,100-foot level - Allis-Chalmers centrifugal, 500-g.p.m., 1,200-foot head.
1,500-foot level - Cameron, 100-g.p.m., 450-foot head.
1,900-foot level - Goulds, 300-g.p.m., 850-foot head.

Each pump is located near its respective shaft station, and operates on 2,300-volt a.c. Pumps are operated periodically.

Drilling Water

Source of water used for drilling underground is mine water. Water is siphoned from the sumps at the shaft stations on various levels and piped down the shaft as required. Open tanks are used to reduce pressures. Pipelines distributing drilling water are commonly 1-1/2 inch in diameter and are installed along main-level drifts and into the working places. Drilling-water pressure is normally maintained at about 40 pounds at the drill.

Wage and Working Agreements

The company used an incentive system to increase the efficiency of labor. The incentive plans, hourly wage rates, and working agreements were incorporated in an agreement between the Inland Steel Co. and the United Steel Workers of America (CIO).

Table 7 shows standard hourly wage rates.

Miners are included in job class 14. The incentive system includes drifting, raising, long-hole drilling, and stoping. In 1957, incentive payments amounted to 25.7 percent of hourly wage payments.

Fire Prevention

Water is provided for fire protection on the surface by a well and pump constituting an independent main water supply. An auxiliary pumping unit is maintained in working condition at another well to augment the water supply, if needed. Water is pumped to an elevated tank, and pipelines are provided to all parts of the surface plant.

An auxiliary pump in the fan house can pump water to the upper floor in the headframe. Hoses are kept on each floor in the headframe, and at other strategic locations in the buildings.

CO_2-type fire extinguishers are at all strategic underground and surface locations. Hoses are available for firefighting at shaft stations. Waterlines are also cross-connected to compressed-air lines at shaft stations so that in emergencies the air lines can be used as waterlines.

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TABLE 7. - Standard hourly wage rates

Job class	Evaluation points	Effective Aug. 5, 1956	Effective July 1, 1957	Effective July 1, 1958
1-2.....	0-11	$1.820	$1.890	$1.960
3.....	12-15	1.883	1.955	2.027
4.....	16-19	1.946	2.020	2.094
5.....	20-23	2.009	2.085	2.161
6.....	24-27	2.072	2.150	2.228
7.....	28-31	2.135	2.215	2.295
8.....	32-35	2.198	2.280	2.362
9.....	36-39	2.261	2.345	2.429
10.....	40-43	2.324	2.410	2.496
11.....	44-47	2.387	2.475	2.563
12.....	48-51	2.450	2.540	2.630
13.....	52-55	2.513	2.605	2.697
14.....	56-59	2.576	2.670	2.764
15.....	60-63	2.639	2.735	2.831
16.....	64-67	2.702	2.800	2.898
17.....	68-71	2.765	2.865	2.965
18.....	72-75	2.828	2.930	3.032
19.....	76-79	2.891	2.995	3.099
20.....	80-83	2.954	3.060	3.166

An auxiliary source of water on surface is the cooling pond near the air compressor. This water source is available for use by a pumping unit in case the city of Ishpeming fire truck is called.

Safety Methods, Mine Rescue, and First-Aid Organization and Training

Mine Rescue

A mine rescue station is maintained at the Morris mine. Greenwood mine personnel are trained jointly with Morris mine teams so that, in event of fire or major accidents, full mine rescue teams are available at either mine.

Mine rescue teams are organized, trained, and equipped to comply with Federal Bureau of Mines recommendations. Mine rescue and first-aid training are conducted by Bureau personnel at the Morris mine for 2 days twice yearly.

Safety Organization

A safety director and an assistant, employed by the Inland Steel Co., direct and perform other functions in safety and welfare programs.

The safety director visits each property at least once each month for a visual inspection of all parts of the property. Accompanying him on such inspections are a foreman of each department visited and a man from the safety committee representing the union. The county mine inspector may accompany them.

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Recommendations made by the inspection team are sent to the superintendent of each mine. The superintendent must then answer in a specified time, stating what actions were taken on the recommendations insofar as they apply to his operation, and giving reasons for the actions.

The safety director also investigates accidents, and checks firefighting equipment and ventilation. He has control of physical examination schedules for men, the personnel receiving compensation insurance, and safety in any new project being undertaken at each property.

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